Rec'd PCT/PTO 27 MAR 2002

BAKER BOTTS L.L.P

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

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U.S. APPLICATION NO 10/089528	

INTERNATIONAL APPLICATION NO	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/EP00/09440	27 SEPTEMBER 2000	06 OCTOBER 1999

TITLE OF INVENTION DIRECT INJECTION INTERNAL COMBUSTION ENGINE WITH NOx-REDUCED EMISSIONS

APPLICANT(S) FOR DO/EO/US Ekkehard Pott, Rudolf Krebs and Bernd Stiebels

Applicant herewith submits to the United States Designated /Elected Office (DO/EO/US) the following items and other information:

1. [✓] This is a FIRST submission of items concerning a filing under 35 U S C 371.
2. [ ] This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U.S.C. 371.
3. [✓] This express request to begin national examination procedures (35 U S.C 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(I).
4. [✓] A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. [✓] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [✓] is transmitted herewith (required only if not transmitted by the International Bureau)
   b. [ ] has been transmitted by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US).
6. [ ] A translation of the International Application into English (35 U.S C. 371(c)(2)).
7. [✓] A copy of the International Search Report (PCT/ISA/210)
   a. [✓] are transmitted herewith (required only if not transmitted by the International Bureau).
   b. [ ] have been transmitted by the International Bureau
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d. [ ] have not been made and will not be made.
8. [ ] A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. [ ] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. [ ] A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. [✓] A copy of the International Preliminary Examination Report (PCT/IPEA/409)
12. [ ] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. [ ] A FIRST preliminary amendment.
    [ ] A SECOND or SUBSEQUENT preliminary amendment.
14. [ ] A substitute specification.
15. [ ] A change of power of attorney and/or address letter.
16. [✓] Other items or information:
    a. [✓] a copy of the International Search Report (PCT/ISA/210)
    b. [✓] a copy of the International Preliminary Examination Report (PCT/IPEA/409)

International Appln WO 01/24505 A1 (incl 9 pages spec , 2 pages claims, 1 page abstract, 4 sheets drawings)
PCT/IPEA/401
PCT/RO/101

10/089548

Rec'd PCT/PTO 27 MAR 2002

INTERNATIONAL APPLICATION NO	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/EP00/09440	27 SEPTEMBER 2000	06 OCTOBER 1999

17. ✔ The following fees are submitted:

CALCULATIONS PTO USE ONLY

Basic National Fee (37 CFR 1.492(a)(1)-(5):

Neither international preliminary examination fee (37 CFR 1 482)
Nor international search fee (37 CFR 1 445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO (1.492(a)(3)) $1,040

International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO (1 492(a)(5) $890.00

International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO(1 492(a)(2)) $740.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) (1.492(a)(1)) $710.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) $ 100.00

ENTER APPROPRIATE BASIC FEE AMOUNT =				$ 890	
Surcharge of $130 00 for furnishing the oath or declaration later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 C.F R. 1.492)(e)).				$	
Claims	**Number Filed**	**Number Extra**	**Rate**	$	
Total Claims	-20=	0	X $ 18.00	$ 0	
Independent Claims	-3=	0	X $ 84.00	$ 0	
Multiple dependent claim(s) (if applicable)			+ $280.00	$	
TOTAL OF ABOVE CALCULATIONS =				$ 890	
Reduction by ½ for filing by small entity, if applicable.				$	
SUBTOTAL =				$ 890	
Processing fee of $130.00 for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$	
TOTAL NATIONAL FEE =				$ 890	
Fee for recording the enclosed assignment (37 CFR 1 21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property +				$	
TOTAL FEES ENCLOSED =				$ 890	
				Amt. refunded	$
				charged	$

a. ✔ A check in the amount of $ 890 to cover the above fees is enclosed

b. [ ] Please charge our Deposit Account No. 02-4377 in amount of $______ to cover the above fees A copy of this sheet is enclosed

c. ✔ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No 02-4377 A copy of this sheet is enclosed

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO
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Attorney JAMES J MAUNE PTO Reg. 26,946

27 MARCH 2002

Date

#4

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	:	Pott et al.	
Serial No.	:	10/089,528	Confirmation No. 7313
Filed	:	March 27, 2002	Group Art Unit:
For	:	DIRECT INJECTION INTERNAL COMBUSTION ENGINE WITH NO_x-REDUCED EMISSIONS	

PRELIMINARY AMENDMENT AND
RESPONSE TO NOTIFICATION TO FILE MISSING PARTS

I hereby certify that this paper is being deposited with the United States Postal Service in an envelope addressed to: Assistant Commissioner for Patents, Washington, D.C. 20231

July 2, 2002
Date of Deposit

James J. Maune
Attorney Name

26,946
PTO Registration No

Signature

July 2, 2002
Date of Signature

Assistant Commissioner for Patents
Box PCT
Washington, D.C. 20231

Sir:

In response to the Notification of Missing Requirements Applicants submit herewith a translation of the application as filed.

Please amend the Application as follows:

IN THE SPECIFICATION:

Please substitute the attached Substitute Specification and Abstract for the translation of this application. The Substitute Specification conforms to U.S. Practice and places the application in better English and U.S. format.

IN THE CLAIMS:

Cancel Claims 1 to 11.

Add claims 12 to 23 as follows:

12. A direct injection internal combustion engine system, comprising:

at least one cylinder having a piston moving along an axis;

a gas inlet and a gas outlet leading to an exhaust passage;

an No_x reducing converter in said exhaust passage; and

intake and exhaust valves associated with said cylinder and said gas inlet and and gas outlet, arranged to provide internal exhaust-gas recirculation;

wherein said cylinder, said gas inlet and said gas outlet are arranged to provide layered lean operation of said engine; and

wherein said inlet passage is arranged to provide swirl in incoming gas having a swirl axis substantially transverse to said piston axis and arranged to cause an intermixture of residual exhaust gas with said incoming gas.

13. An engine system as specified in claim 12 wherein said inlet passage is arranged to provide a swirl that is a tumble movement.

14. Internal combustion engine according to Claim 13 wherein a tumble plate is provided in said gas inlet.

15. Internal combustion engine according to claim 12 wherein said engine is an Otto engine.

16. Internal combustion engine according to claim 12 wherein said inlet passage is arranged for a layered charging.

17. Internal combustion engine according to claim 12 wherein there is further provided an arrangement for external exhaust-gas recirculation.

18. Internal combustion engine according to Claim 17, wherein the external exhaust-gas recirculation arrangement includes an arrangement for cooling recirculated gases.

19. Internal combustion engine according to Claim 17, wherein the external exhaust-gas recirculation arrangement includes a control valve.

20. Internal combustion engine according to claim 12 wherein the swirl has an axis which lies in the region of 75° to 105° of said piston axis.

21. Internal combustion engine according to claim 12 wherein said reducing converter comprises a NOx storage catalyst.

22. Internal combustion engine according to claim 21 wherein said storage catalyst is controlled by a NOx sensor.

23. Internal combustion engine according to claim 12 wherein there is provided an arrangement for controlling internal exhaust-gas recirculation by adjustment of intake valve opening times in the direction of early.

REMARKS

Applicants submit herewith a translation of the application as filed and a proposed Substitute Specification and Abstract in compliance with U.S. Practice.

Claims 1 to 11 are cancelled. Claims 12 to 23 conforming to U.S. practice are presented.

A Declaration and Power of Attorney are submitted herewith.

Respectfully submitted,

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PTO/PCT Rec'd 02 JUL 2002 10/089528
PATENT
A35111-PCT-USA 070255.0624

Substitute Specification

Direct injection internal combustion engine with reduced NOx emissions

BACKGROUND OF THE INVENTION

[0001] The invention relates to a direct injection internal combustion engine.

[0002] EP 0,560,991 B and EP 0,580,389 B disclose means for NOx reduction in internal combustion engines with lean operation. The principle applied is storage of the NOx produced, especially during lean operation of the engine, in a NOx storage catalyst and release of the stored NOx with simultaneous reduction by brief rich operation of the engine. This NOx conversion is also suitable especially in direct injection internal combustion engines. The NOx conversion allows relatively high conversion rates to be obtained where, especially for avoidance of raw NOx emissions, exhaust-gas recirculation may be used in combination with the NOx storage catalyst.

[0003] Exhaust-gas recirculation reduces raw NOx emissions. This measure is especially important in direct injection Otto engines with a NOx–reducing exhaust-gas aftertreatment system in lean operation, in particular NOx storage catalysts, since the lean conversion may break down very high raw NOx emissions, as occur particularly in homogeneous lean operation at lambda = 1.1 to 1.4 or also in layered lean operation at lambda = 1.6 to 4, even with the use of NOx storage catalysts, possibly as a result of inhibition of diffusion at the surface of the storage catalyst.

[0004] In addition, the recirculated exhaust gas leads to retardation in combustion, which, owing to the reduced temperature of combustion, also acts to reduce NOx and produces an improvement in fuel consumption, since the effective position of fuel

conversion, which in direct injection Otto engines in layered lean operation typically is too early in the cycle, is shifted in the direction of the optimal position.

[0005] In addition, the hot recirculated exhaust gas, with suitable metering, may also lead to the stabilization of combustion in layered lean operation, since mixture formation, which must proceed on very small time scales owing to late injection in this type of operation, is supported by the increased temperature of exhaust-gas recirculation.

[0006] However, the portion of recirculated exhaust gas in the combustion chamber should not be too high, in order to provide enough fresh gas for the combustion of fuel. When exhaust-gas recirculation rates are too high, incomplete combustion takes place, owing to which fuel consumption and HC/CO emissions increase and the quietness of operation of the engine decreases.

[0007] The external exhaust-gas recirculation usually carried out, i.e., tapping of exhaust gas after the combustion chamber, in particular at the exhaust-gas manifold, and return to the intake side of the engine, permits homogeneous distribution of the exhaust gas to the individual cylinders by structural means only at great cost. In addition, the exhaust-gas recirculation rate in the dynamic operation present in an internal combustion engine, due to the time delay in the exhaust-gas recirculation line and the intake volume and the changing pressure conditions in the intake and exhaust-gas sides, is hard to adapt and adjust to desired specifications. Accordingly, the exhaust-gas recirculation rate may vary considerably among individual cylinders and a drop below undesired minimal values or exceeding undesired maximum values cannot be ruled out.

[0008] Alternatively or in addition to external exhaust-gas recirculation, internal exhaust-gas recirculation is well known, in which due to displacement of intake and

exhaust times with respect to each other by displacement of intake camshafts in the direction of "EARLY", retention of a residual gas portion in the cylinder is made possible. The advantage of this method is that, in addition to accurate distribution to individual cylinders, the residual gas already participates in the next combustion operation and the dead times described above, and the large deviations from a desired specification, largely disappear. Because of the high temperature of the internally recirculated exhaust gas, the influence on mixture formation is also more definite and can be used more selectively.

[0009] The advantages described of internal exhaust-gas recirculation are utilized in the first direct injection DI Otto engines found on the market, which in addition to external exhaust-gas recirculation also have internal exhaust-gas recirculation with intake camshaft displacement and exhaust-gas purification by means of NOx storage catalysts. For mixture formation in these internal combustion engines, a swirl concept is used for charging, in which a rotational movement is imparted to the drawn-in gases in the cylinder, the axis of rotation running approximately parallel to the piston movement/cylinder axis. At the same time, a vertical swirl is produced in the combustion chamber, into which the stream of fuel is injected and conveyed to the spark plug. In conjunction with a NOx storage catalyst, such combustion processes already have quite low NOx emissions.

[0010] The object of the present invention is to optimize, in a direct injection internal combustion engine with NOx-reducing exhaust-gas aftertreatment, the course of combustion together with exhaust-gas aftertreatment so that especially low NOx emission values are obtained.

SUMMARY OF THE INVENTION

[0011] According to the invention, a special combination of individual exhaust gas-reducing steps allows an especially low emission of pollutants, particularly of NOx, to be obtained, so that now very low exhaust gas standards, such as for example D4, can be achieved even in direct injection internal combustion engines. This is made possible in a direct injection internal combustion engine by internal exhaust-gas recirculation (EGR), in particular in combination with external EGR, NOx-reducing exhaust-gas aftertreatment as well as a swirling movement of the incoming (fresh) gases, which runs substantially transverse to the axis of piston movement. Preferably, a tumble movement of the incoming gases is provided, which advantageously is produced by a tumble plate in the intake channel. In such a tumble movement, the incoming gases tumble rolling into the cylinder interior, the rolling movement proceeding about an axis transverse to the piston movement. The tumble plate advantageously is used with an as-needed switch from flow with tumble swirl to ordinary filling of the cylinder chamber, as is customary in for example lambda-1 operation (regeneration of storage catalyst, high engine load).

[0012] The combination of internal EGR with external EGR permits an increase in the exhaust-gas recirculation rate, so that the engine can operate with very low excess oxygen. Here, it is additionally possible to cool external EGR by means of an exhaust-gas recirculation cooler, so that the combustion chamber temperature does not get too high. External EGR is usually controlled by means of a valve.

[0013] According to the invention, the swirl axis preferably lies in a region of ±15° of the piston movement, the lowest NOx emissions being produced in this region.

[0014] In particular, according to the invention a NOx storage catalyst, which stores the nitrogen oxides of the raw exhaust-gas emissions for several seconds (usually for up to about 2 min.) as for example barium nitrate, and is regenerated with reduction during operation at lambda 1 (or alternatively a little for lambda = 1), is used for NOx-reducing exhaust-gas aftertreatment. Such storage catalysts are disclosed in the European patents mentioned above.

[0015] With the present invention, a NOx sensor after the NOx-reducing step of exhaust-gas aftertreatment, may be used especially favorably, in particular in conjunction with a storage catalyst. In previous operating systems without the tumble movement, slight excess NOx emissions were possible, which were incorrectly evaluated by the NOx sensor as indicating that the storage catalyst needed to be regenerated, so that fuel consumption-increasing regeneration took place more than needed. NOx peaks are avoided by the use of the tumble gas movement, so that the NOx sensor after the storage catalyst signals permissible storage rates and hence storage-fill condition of the NOx storage catalyst only.

[0016] It has been found according to the invention that for optimal NOx reduction, as thorough as possible intermixing of the recirculated waste gas with fresh air should be obtained, since only in this way can the oxygen molecules participating in NOx formation be partially replaced by inert gas (exhaust gas) in the whole combustion chamber. According to the invention, production of rapidly burning local zones with a high percentage of oxygen, which contribute dis-proportionately to NOx formation, are avoided. This is of importance especially in the direct injection Otto engine, in order to

be able to realize the advantages of internal exhaust-gas recirculation as much as possible.

[0017] The invention will be described in detail by means of an example.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a combustion course according to the prior art (swirl concept).

Figure 2 shows the combustion course (tumble concept) according to the invention.

Figure 3 is a graphic representation of the two concepts.

Figure 4 is a general representation of the an engine system according to the invention.

DESCRIPTION OF THE INVENTION

[0018] Studies according to the invention have shown that the mixture of fresh air 6 with exhaust gas 3 of internal exhaust-gas recirculation remaining in the combustion chamber 1 (Fig. 1a, piston 2 is at the top, exhaust gas 3 remains in the combustion chamber 1 owing to simultaneously open intake and exhaust valves (Fig. 4)) is suboptimal with swirl turbulence 7 wherein the swirl axis is aligned substantially to the axis of piston movement. The residual gas 3 of the internal EGR remains in the vicinity of the piston floor during the intake and compression strokes (Fig. 1b/c), due to the action of the swirl flow 7, the fresh gas 3 drawn in (containing predominantly fresh air) is then layered over the residual gas 3 in the intake stroke (Fig. 1b, piston 2 travels downward). Since the swirling gas movement 7 has only a few pulses in the direction of the piston movement, this layering (without substantial intermixing) is largely maintained during

compression (Fig. 1c, piston travels upward). The fuel 8 injected toward the end of compression (injection nozzle not shown) is injected partly into almost pure fresh air 6, partly into inhomogeneous mixed zones 5 with varying fresh air-residual gas proportions, and partly into almost pure residual gas 3 (Fig. 1c). During conversion (ignited by spark plug 4), residual gas portions varying from near 0% to near 100% may thus appear in the flame front, the almost optimal residual gas portion being present locally only in small regions of the combustion chamber 1, although the overall portion of residual gas may correspond to the desired specifications. In zones with no or little residual gas, the fuel burns rapidly and at high temperatures, so that no signifcant NOx reduction occurs. In zones with a very high percentage of residual gas, fuel conversion breaks down, so that the exhaust gas, in addition to having only small NOx reduction, may show elevated HC emissions and a reduction in work delivered. In addition, increased fuel consumption as well as noisy operation may occur, leading to a drop in the desired specification for the exhaust-gas recirculation rate, and hence, decreased NOx-reduction potential. Although in principle it is also possible to take this layering into account in the swirl movement, by for example designing the floor of the piston so that either swirling commences again on compression or the injected stream reaches as homogeneous as possible a region, according to the invention it has been discovered that providing a tumble swirl permits better, i.e., lower NOx emission values, to be obtained, especially in conjunction with a NOx sensor.

[0019] Depending on exhaust-gas concept, the resulting high HC and NOx emissions can be reduced, particularly by selective catalytic reduction, i.e., reciprocal reduction and oxidation, so that on the whole relatively low exhaust-gas emission values

can again be achieved, but only at the expense of fuel consumption and quietness of operation of the engine.

[0020] As shown in Fig. 2, according to the invention internal exhaust-gas recirculation also takes place (as in Fig. 1) via displacement of the intake camshaft but with a tumble charging movement concept 17, wherein the axis of rotation of the drawn-in gas lies largely transverse to the piston movement. At the beginning of the intake stroke (Fig. 2a, piston 12 is at the top), a high residual gas portion 13, as in Fig. 1a, is found in the cylinder chamber 11. However, in contrast to the prior art, the method according to the invention has the advantage that the subsequent charging movement (Fig. 2b) results in intensive intermixing of the residual exhaust-gas portion 13 with the fresh gas 16 drawn in (optionally enriched with exhaust gas owing to external exhaust-gas recirculation). As can be seen in Fig. 2c, the injected fuel 18 thus encounters a gas mixture whose local residual gas portion differs only slightly from the average (overall) residual exhaust-gas portion (largely homogeneous mixture 15). This prevents extinction of the flame (ignited via spark plug 14) because of excess local residual exhaust-gas portions, and leads to ideal NOx reduction in the raw exhaust gas without increasing HC emissions, with low operation noise and low fuel consumption. As a result, a higher proportion for the residual exhaust gas content of the charge may be used.

[0021] Fig. 3 is a graph showing the small variation of the residual exhaust-gas content in the combustion chamber. The overall residual exhaust-gas portion in the combustion chamber is labeled 30.

[0022] 31 indicates the undesired region of too little NOx reduction (too much O_2); 32 shows the undesired region of deficient fuel conversion (higher CO/HC production). Curve 33 represents the tumble concept; curve 34 shows greater non-homogeneity from the swirl concept. According to the invention, even at a high exhaust-gas recirculation rate, local excess of the maximum permissible residual exhaust-gas portion is largely avoided in the tumble concept.

[0023] The general concept is represented in Fig. 4, which shows a section in the internal combustion engine 50, which has a gas inlet 51, through which, in layer-charging operation, the incoming fresh gases, together with exhaust gases recirculated via an exhaust-gas recirculation line 68, have passed into the combustion cylinder 11 in a tumble flow 17, via a tumble plate 52. The re-circulated exhaust gases are controlled via a valve 67 by the engine control 66 according to operating conditions and in addition are cooled via an EGR cooler 69. As in Fig. 2c, the compression stroke, in which the fuel 18 is injected, is represented. The engine 50 additionally has an intake camshaft 55 and an exhaust camshaft 56, which via levers 54 and 57 actuate the intake valves 53 and exhaust valves 59. The latter are accommodated in the cylinder head 58. Filling of the combustion chamber 11 with exhaust gas 13 is obtained by opening of the valves 53 and 59 (Fig. 2a). The valves 53 and 59 are closed during the compression stroke.

[0024] After combustion has taken place, the piston 12 again travels downward and the exhaust valves 59 are opened, so that the exhaust gases 60 flow into the exhaust manifold 70. In doing so, they flow past a lambda probe 61, which is designed as a broadband lambda probe and serves for determination of the lambda value from rich to lean. The exhaust gases then flow through a preliminary catalyst 62, which is designed

as a 3-way catalyst. Here, CO and HC are converted to CO_2 and H_2O by the oxygen present, and, in addition, oxidation from NO to NO_2 takes place. A temperature sensor 63, which serves for monitoring (OBD) of the catalyst 62, is arranged after the preliminary catalyst 62. In the further course, the exhaust gases flow into a NOx storage catalyst 64, which absorbs the nitrogen oxides. With increasing degree of fill, increased NOx passes through the NOx storage catalyst 64 and is detected by the NOx sensor 65. This signal is assessed by the engine control 66 as meaning that, when a given value is exceeded, regeneration of the NOx storage catalyst 64 should take place. This is done by brief (up to about 5 sec.) rich operation of the engine 50, during which increased levels of H_2, CO and HC enter the NOx storage catalyst 64 and react with the stored NOx to form N_2, H_2O and CO_2. Following regeneration, engine operation is switched back to lean operation.

[0025] Regeneration as well as high-load operation advantageously are carried out under homogeneous operating conditions of the engine 50, in which the oncoming flow 71 from the tumble plate 52 is flattened (laid on the wall of the intake channel 51), so that the fresh gases flow past the tumble plate 52 and as a result no tumble swirl takes place in the combustion chamber 11.

[0026] In a direct injection internal combustion engine, especially an Otto engine, with layered lean operation and internal exhaust-gas recirculation, NOx-reducing exhaust-gas aftertreatment is provided by means of a NOx storage catalyst. To obtain as high as possible exhaust-gas recirculation rates with as low as possible HC and NOx emission values, a tumble flow is provided for the incoming fresh gases, which optionally may contain recirculated exhaust gas from external exhaust-gas recirculation, so that the swirl

axis of the incoming fresh gases runs substantially transverse to the piston movement. In this way, an optimal emission-reducing mixture of the internal chamber of the cylinder is obtained in layered lean operation.

[0027] While there have been described what are believed to be the preferred embodiments of the invention those skilled in the art will recognize that other changes and modifications may be made thereto without departing from the spirit of the invention, and it is intended to claim all such changes and modifications as fall within the true scope of the invention.

ABSTRACT

A direct injection internal combustion engine, especially an Otto engine, is provided with layered lean operation and internal exhaust-gas recirculation. An exhaust-gas aftertreatment for reducing Nox using an Nox storage catalyst is also provided. This combination is to achieve the highest possible exhaust-gas recirculation rates with the lowest HC and Nox emission values. A tumble flow is provided for the incoming fresh gases, which may contain recirculated exhaust gas from external exhaust-gas recirculation. The swirl axis of the incoming fresh gases therefore extends substantially crosswise to the piston movement. This results in an emissions-reducing, optimal mixture inside the cylinder during the layered lean operation.

#4

[Translation from German]

WO 01/25605 A1

K 8379 PCT-vb

Direct injection internal combustion engine with reduced NOx emissions

The invention relates to a direct injection internal combustion engine according to the generic clause of Claim 1.

EP 0,560,991 B and EP 0,580,389 B disclose means for NOx reduction in internal combustion engines with lean operation. The principle here is storage of the NOx produced, especially during lean operation of the engine, in a NOx storage catalyst and release of the stored NOx with simultaneous reduction by brief rich operation of the engine. This NOx conversion is also suitable especially in direct injection internal combustion engines. The NOx conversion described allows relatively high conversion rates to be obtained where, especially for avoidance of raw NOx emissions, exhaust-gas recirculation may be used in combination with the NOx storage catalyst.

Exhaust-gas recirculation definitely clearly reduces raw NOx emissions. This measure is especially important in direct injection Otto engines with a NOx–reducing exhaust-gas aftertreatment system in lean operation, in particular NOx storage catalysts, since the lean conversion may break down very high raw NOx emissions, as occur particularly in homogeneous lean operation at lambda = 1.1

to 1.4 or also in layered lean operation at lambda = 1.6 to 4, even with the use of NOx storage catalysts, possibly as a result of inhibition of diffusion at the surface of the storage catalyst.

In addition, the recirculated exhaust gas leads to retardation in combustion, which, for one thing, owing to the reduced temperature of combustion, likewise acts to reduce NOx and, for another, produces an improvement in fuel consumption, since the effective position of fuel conversion, which in direct injection Otto engines in layered lean operation typically is too early in the cycle, is shifted in the direction of the optimal position.

In addition, the hot recirculated exhaust gas, with suitable metering, may also lead to the stabilization of combustion in layered lean operation, since mixture formation, which essentially must proceed on very small time scales owing to late injection in this type of operation, is supported by the increased temperature of exhaust-gas recirculation.

However, the portion of recirculated exhaust gas in the combustion chamber may not be selected too high either, in order to provide enough fresh gas for the combustion of fuel. When exhaust-gas recirculation rates are too high, incomplete combustion takes place, owing to which consumption and HC/CO emissions increase again and the quietness of operation of the engine decreases.

The external exhaust-gas recirculation usually carried out (tapping of exhaust gas after the combustion chamber, in particular at the exhaust-gas manifold, and return to the intake side of the engine) permits homogeneous

distribution of the exhaust gas to the individual cylinders by structural means only at great cost. In addition, the exhaust-gas recirculation rate in the dynamic operation present particularly in an internal combustion engine, due to the time delay in the exhaust-gas recirculation line and the intake volume and the changing pressure conditions in the intake and exhaust-gas sides, is hard to adapt and adjust to desired specifications. Accordingly, the exhaust-gas recirculation rate may vary considerably among individual cylinders and a drop below undesired minimal values or excedence of undesired maximum values cannot always be ruled out.

Alternatively or in addition to external exhaust-gas recirculation, internal exhaust-gas recirculation is well known, in which due to displacement of intake and exhaust times to one another, in particular by displacement of intake camshafts in the direction of "EARLY", retention of a residual gas portion in the cylinder is made possible. The advantage of this method is that, in addition to accurate metering to individual cylinders, the residual gas already participates in the next combustion operation and the dead times described above, as well as the great deviations from a desired specification, largely disappear. Because of the high temperature of the internally recirculated exhaust gas, the influence on mixture formation is also more definite and can be used more selectively.

The advantages described of internal exhaust-gas recirculation are utilized in the first direct injection DI Otto engines found on the market, which in addition to external exhaust-gas recirculation also have internal exhaust-gas recirculation with intake camshaft displacement and exhaust-gas purification by means of

NOx storage catalysts. For mixture formation in these internal combustion engines, a swirl concept is used for charging, in which a rotational movement is imparted to the drawn-in gases in the cylinder, the axis of rotation running approximately parallel to the piston movement/cylinder axis. At the same time, a vertical swirl is produced in the combustion chamber, into which the stream of fuel is injected and conveyed to the spark plug. In conjunction with a NOx storage catalyst, such combustion processes already have quite low NOx emissions.

The object of the present invention is to optimize, in a direct injection internal combustion engine with NOx-reducing exhaust-gas aftertreatment, the course of combustion together with exhaust-gas aftertreatment so that especially low NOx emission values are obtained.

The present invention accomplishes this object by the combination of features according to Claim 1.

The dependent claims describe additional features by which, individually as well as in combination, especially favorable emission values can be obtained.

According to the invention, a special combination of individual exhaust gas-reducing steps allows an especially low emission of pollutants, particularly of NOx, to be obtained, so that now very low exhaust gas standards, such as for example D4, can be obtained even in direct injection internal combustion engines. This is made possible in a direct injection internal combustion engine by internal exhaust-gas recirculation (EGR), in particular in combination with external EGR, NOx-reducing exhaust-gas aftertreatment as well as a swirling

movement of the incoming (fresh) gases, which runs substantially transverse to the piston movement. Preferably, a tumble movement of the incoming gases is used here, which advantageously is produced by a tumble plate in the intake channel. In such a tumble movement, the incoming gases tumble rolling into the cylinder interior, the rolling movement proceeding about an axis transverse to the piston movement. The tumble plate advantageously is used with an as-needed switch from flow with tumble swirl to ordinary filling of the cylinder chamber, as is customary in for example lambda-1 operation (regeneration of storage catalyst, high engine load).

The combination of internal EGR with external EGR permits an additional increase to be obtained in the exhaust-gas recirculation rate, so that the engine can operate with very low excess oxygen. Here, it is additionally possible to cool external EGR by means of an exhaust-gas recirculation cooler, so that the combustion chamber temperature does not get too high. External EGR is usually controlled by means of a valve.

According to the invention, the swirl axis preferably lies in a region of ±15° of the piston movement, the lowest NOx emissions being produced in this region.

In particular, according to the invention a NOx storage catalyst, which stores the nitrogen oxides of the raw exhaust-gas emissions for several seconds (usually for up to about 2 min.) as for example barium nitrate, and is regenerated with reduction during operation at lambda ≤ 1 (or alternatively a little for lambda = 1), is used for NOx-reducing exhaust-gas aftertreatment. Such storage catalysts are disclosed in the European patents mentioned at the beginning.

With the present invention, a NOx sensor after the NOx-reducing step of exhaust-gas aftertreatment, may be used especially favorably, in particular in conjunction with a storage catalyst. In previous operating systems without the tumble movement, slight NOx breakthroughs were possible, which were incorrectly evaluated by the NOx sensor as storage catalyst to be regenerated, so that too often fuel consumption-increasing regeneration took place. NOx peaks have been avoided only by the use of the tumble movement, so that the NOx sensor after the storage catalyst signals permissible storage rates and hence storage-fill degrees of the NOx storage catalyst only according to the invention.

It has been found according to the invention that for optimal NOx reduction, as thorough as possible intermixing of the recirculated waste gas with fresh air should be obtained, since only in this way can the oxygen molecules participating in NOx formation be partially replaced by inert gas (exhaust gas) in the whole combustion chamber. According to the invention, production of rapidly burning local zones with a high percentage of oxygen, which contribute disproportionately to NOx formation, is avoided. This peculiarity is of importance especially in the direct injection Otto engine, in order to be able to utilize the potential of internal exhaust-gas recirculation as much as possible.

The invention will be described in detail by means of an example and figures, wherein

Figure 1 shows a combustion course according to the prior art (swirl concept);

Figure 2, the combustion course (tumble concept) according to the invention;

Figure 3, a graphic representation of the two concepts; and

Figure 4, a general representation of the concept according to the invention.

Studies according to the invention have shown that the mixture of fresh air 6 with exhaust gas 3 of internal exhaust-gas recirculation remaining in the combustion chamber 1 (Fig. 1a, piston 2 is at the top, exhaust gas 3 remains in the combustion chamber 1 owing to simultaneously open intake and exhaust valves (Fig. 4)) is suboptimal with swirl turbulence 7 (swirl axis aligned substantially to the piston movement/cylinder axis). The residual gas 3 of the internal EGR remains in the vicinity of the piston floor during the intake and compression strokes (Fig. 1b/c), due to the action of the swirl flow 7, the fresh gas 3 drawn in (containing predominantly fresh air) is then layered over the residual gas 3 in the intake stroke (Fig. 1b, piston 2 travels downward). Since the swirling gas movement 7 has only a few pulses in the direction of the piston movement, this layering (without substantial intermixing) is largely maintained during compression (Fig. 1c, piston travels upward). The fuel 8 injected toward the end of compression (injection nozzle not shown) is injected partly into almost pure fresh air 6, partly into nonhomogeneous mixed zones 5 with varying fresh air-residual gas proportions and partly into almost pure residual gas 3 (Fig. 1c).

During conversion (ignited by spark plug 4), residual gas portions of from near 0% to near 100% may thus appear in the flame front, the almost optimal residual gas portion being present locally only in small regions of the combustion chamber 1, although the overall portion of residual gas may correspond perfectly to the desired specifications. In zones with no or little residual gas portions, the fuel percentage burns rapidly and at high temperatures, so that no signifcant NOx reduction occurs here. In zones with a very high percentage of residual gas, fuel conversion breaks down, so that the exhaust gas, in addition to only small NOx reduction may show elevated HC emissions and a reduction in work delivered. In addition, increased consumption as well as deterioration in quietness of operation may occur, which lead to a drop in the desired specification for the exhaust-gas recirculation rate and hence further narrow NOx-reduction potential. Although in principle it is also possible to take this layering into account in the swirl movement, by for example designing the floor of the piston so that either swirling commences again on compression or the injected stream reaches as homogeneous as possible a region, according to the invention it has been found that changing to tumble swirl permits better, i.e., lower NOx emission values, to be obtained, especially in conjunction with a NOx sensor.

Depending on exhaust-gas concept, the resulting high HC and NOx emissions can be reduced, particularly by selective catalytic reduction, i.e., reciprocal reduction and oxidation, so that on the whole relatively low exhaust-gas emission values can again be obtained, but this is at the expense of consumption and quietness of operation of the engine.

As shown in Fig. 2, according to the invention internal exhaust-gas recirculation also takes place (as in Fig. 1) via displacement of the intake camshaft but with a tumble charging movement concept 17 (the axis of rotation of the drawn-in gas lies largely transverse to the piston movement). At the beginning of the intake stroke (Fig. 2a, piston 12 is at the top), a high residual gas portion 13, as in Fig. 1a, is found in the cylinder chamber 11. However, in contrast to the prior art, the method according to the invention has the advantage that the subsequent charging movement (Fig. 2b) results in intensive intermixing of the residual exhaust-gas portion 13 with the fresh gas 16 drawn in (optionally enriched with exhaust gas owing to external exhaust-gas recirculation). As can be seen in Fig. 2c, the injected fuel 18 thus encounters a gas mixture whose local residual gas portion differs only a little from the average (overall) residual exhaust-gas portion (largely homogeneous mixture 15). This prevents extinction of the flame (ignited via spark plug 14) because of too high local residual exhaust-gas portions and at the same time leads to ideal NOx reduction in the raw exhaust gas without increasing HC emissions, with high quietness of operation and low consumption. As a result, higher desired specifications may be set for the residual exhaust gas portion in the fresh gas.

This is shown in Fig. 3, in which the small spread of local variance of the residual exhaust-gas portion in the combustion chamber can be seen. The overall residual exhaust-gas portion in the combustion chamber is labeled 30. 31 indicates the undesired region of too little NOx reduction (too much O_2);

32 shows the undesired region of deficient fuel conversion (CO/HC production, too much exhaust gas). Curve 33 stands for the tumble concept; curve 34 shows greater non-homogeneity with the swirl concept. According to the invention, even at a high exhaust-gas recirculation rate, local excedence of the maximum permissible residual exhaust-gas portion is largely avoided in the tumble concept.

The general concept represented in Fig. 4 shows a section in the internal combustion engine 50, which has a fresh-air intake channel 51, through which, in layer-charging operation, the incoming fresh gases, together with exhaust gases recirculated via an exhaust-gas recirculation line 68, have passed into the combustion chamber 11 in a tumble flow 17, via a tumble plate 52. The re-circulated exhaust gases are controlled via a valve 67 by the engine control 66 according to operating conditions and in addition are cooled via an EGR cooler 69. As in Fig. 2c, the compression stroke, in which the fuel 18 is injected, is represented. The engine 50 additionally has an intake camshaft 55 and an exhaust camshaft 56, which via levers 54 and 57 actuate the intake valves 53 and exhaust valves 59. The latter are accommodated in the cylinder head 58. Filling of the combustion chamber 11 with exhaust gas 13 is obtained by opening of the valves 53 and 59 (Fig. 2a). The valves 53 and 59 are closed during the compression stroke.

After combustion has taken place, the piston 12 again travels downward and the exhaust valves 59 are opened, so that the exhaust gases 60 flow into the exhaust manifold 70. In doing so, they flow past a lambda probe 61, which is designed as a broadband lambda probe and serves for determination of the

lambda value from rich to lean. The exhaust gases then flow through a preliminary catalyst 62, which is designed as a 3-way catalyst. Here, CO and HC can already be converted to CO_2 and H_2O by the oxygen present, and, in addition, oxidation from NO to NO_2 takes place. A temperature sensor 63, which serves for monitoring (OBD) of the catalyst 62, is arranged after the preliminary catalyst 62. In the further course, the exhaust gases flow into a NOx storage catalyst 64, which absorbs the nitrogen oxides in particular. With increasing degree of fill, increasing NOx slip through the NOx storage catalyst 64 takes place, which is detected by the NOx sensor 65. This signal is assessed by the engine control 66 as meaning that, when a given value is exceeded, regeneration of the NOx storage catalyst 64 has to take place. This is done by brief (up to about 5 sec.) rich operation of the engine 50, where H_2, CO and HC go into the NOx storage catalyst 64 and react with the NOx released under these operating conditions to form N_2, H_2O and CO_2. Then operation is switched back to lean operation again.

Regeneration as well as high-load operation advantageously are carried out under homogeneous operating conditions of the engine 50, in which the oncoming flow 71 of the tumble plate 52 is flattened (laid on the wall of the intake channel 51), so that the fresh gases of the tumble plate 52 flow past and as a result no tumble swirl takes place in the combustion chamber 11.

In a direct injection internal combustion engine, especially an Otto engine, with layered lean operation and internal exhaust-gas recirculation, NOx-reducing exhaust-gas aftertreatment is provided by means of a NOx storage catalyst.

To obtain as high as possible exhaust-gas recirculation rates with as low as possible HC and NOx emission values, a tumble flow is provided for the incoming fresh gases, which optionally may contain recirculated exhaust gas from external exhaust-gas recirculation, so that the swirl axis of the incoming fresh gases runs substantially transverse to the piston movement. In this way, an optimal emission-reducing mixture of the internal chamber of the cylinder is obtained in layered lean operation.

ART 34 AMDT

CLAIMS

1. Direct injection internal combustion engine having
   NOx-reducing exhaust-gas aftertreatment,
   internal exhaust-gas recirculation,
   layered lean operation and
   swirl in the incoming fresh gas,
   having a swirl axis running substantially transverse to the piston movement **characterized in that** due to charging an intermixture of the residual exhaust-gas portion with the fresh air drawn in takes place.

2. Internal combustion engine according to Claim 1, **characterized in that** the swirl is a tumble movement.

3. Internal combustion engine according to Claim 1 or 2, **characterized in that** the swirl is produced by a tumble plate in the intake channel.

4. Internal combustion engine according to any of the preceding claims, **characterized in that** it is ignited externally and is an Otto engine.

5. Internal combustion engine according to any of the preceding claims, **characterized in that** a layer charging operation is provided.

6. Internal combustion engine according to any of the preceding claims, **characterized in that** it additionally has external exhaust-gas recirculation.

7. Internal combustion engine according to Claim 5, **characterized in that** the external exhaust-gas recirculation is cooled and/or provided with a control valve.

AMENDED SHEET

ART 34 AMDT

8. Internal combustion engine according to any of the preceding claims, **characterized in that** the swirl axis lies in the region of 75° to 105° of the piston movement.

9. Internal combustion engine according to any of the preceding claims, **characterized in that** exhaust-gas aftertreatment takes place by means of a NOx storage catalyst.

10. Internal combustion engine according to any of the preceding claims, **characterized in that** exhaust-gas aftertreatment is controlled by a NOx sensor.

11. Internal combustion engine according to any of the preceding claims, **characterized in that** internal exhaust-gas recirculation takes place by adjustment of intake valve opening times in the direction of early.

AMENDED SHEET

ABSTRACT

Direct injection internal combustion engine with reduced NOx emissions

The invention relates to a direct injection internal combustion engine, especially an Otto engine, with layered lean operation and internal exhaust-gas recirculation. According to the invention, exhaust-gas aftertreatment for reducing NOx using a NOx storage catalyst is provided. The object of the invention is to obtain the highest possible exhaust-gas recirculation rates with the lowest HC and NOx emission values. To this end, a tumble flow is provided for the incoming fresh gases, which may contain recirculated exhaust gas from external exhaust-gas recirculation. The swirl axis of the incoming fresh gases therefore runs substantially transverse to the piston movement. This results in an emissions-reducing, optimal mixture inside the cylinder during layered lean operation.

[Key to text in Fig. 3:]

Häufigkeit	=	Frequency
lokaler Restgasanteil	=	Local residual gas portion

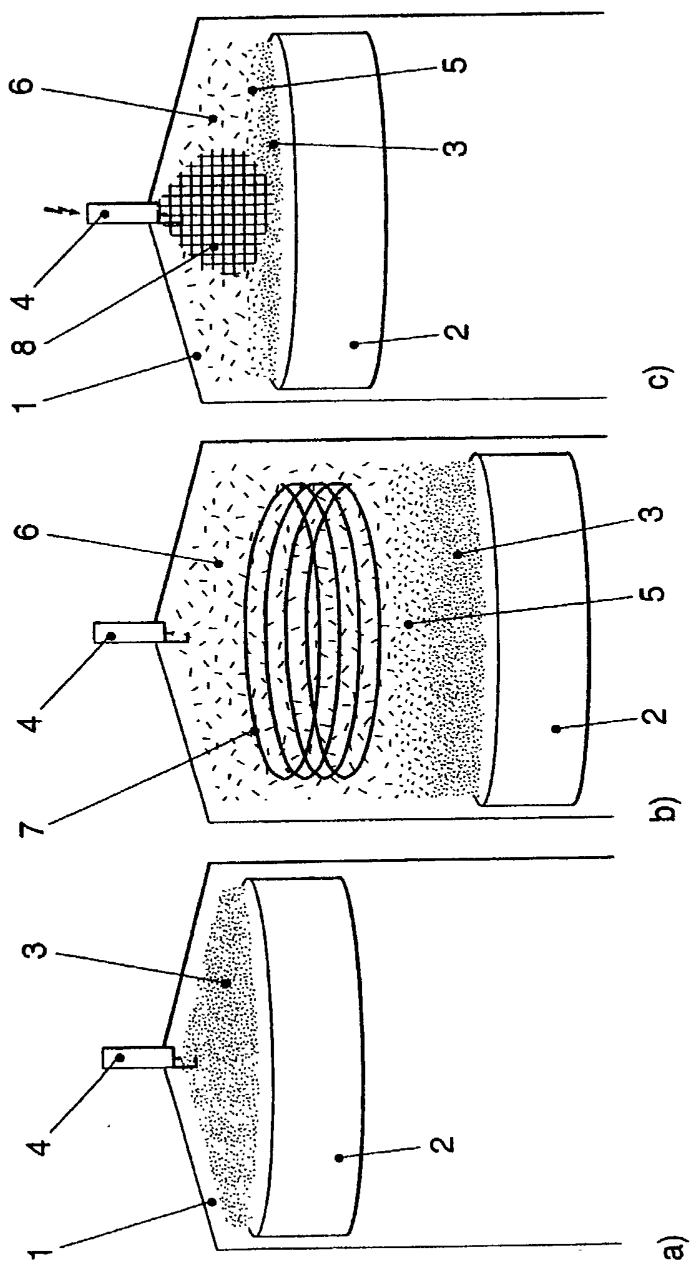

FIG. 1

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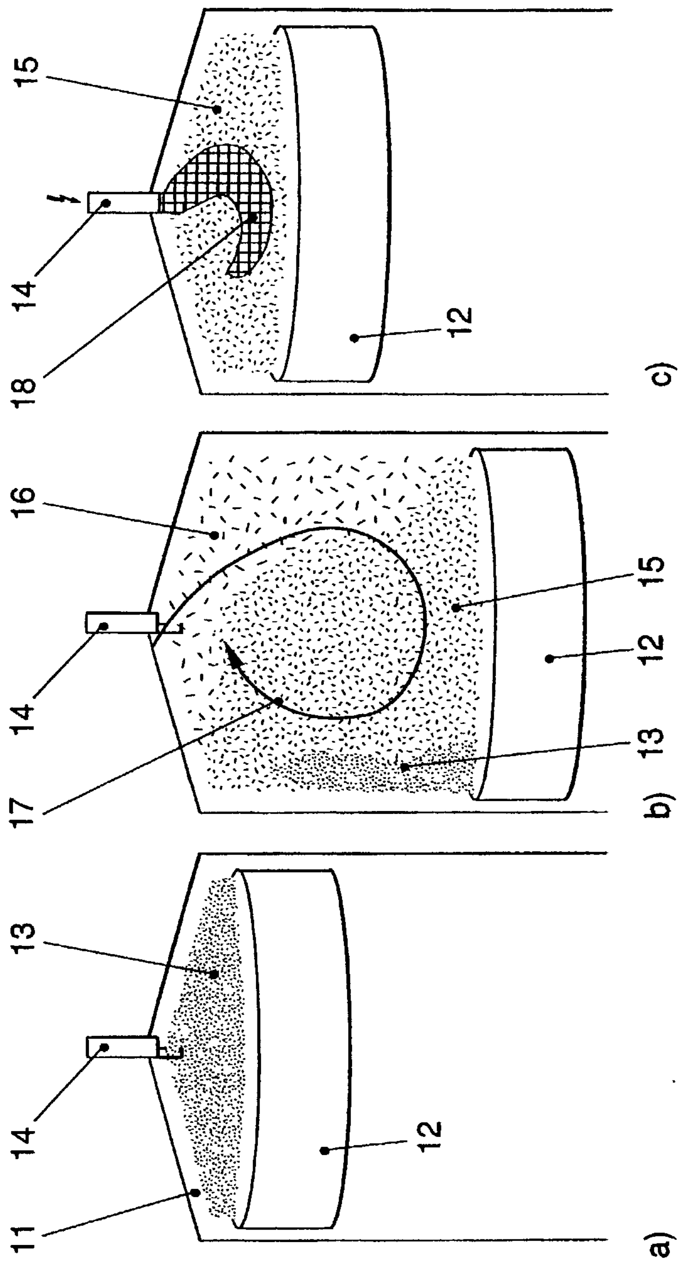

FIG. 2

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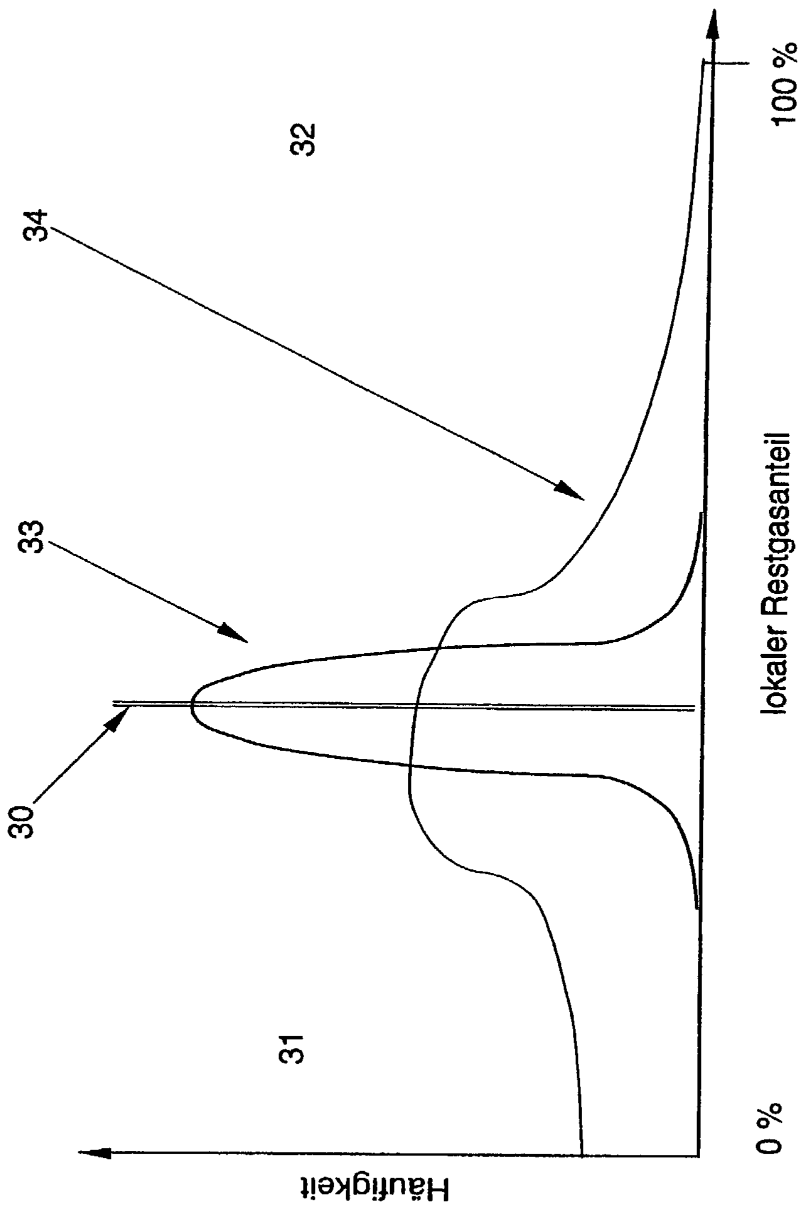

FIG. 3

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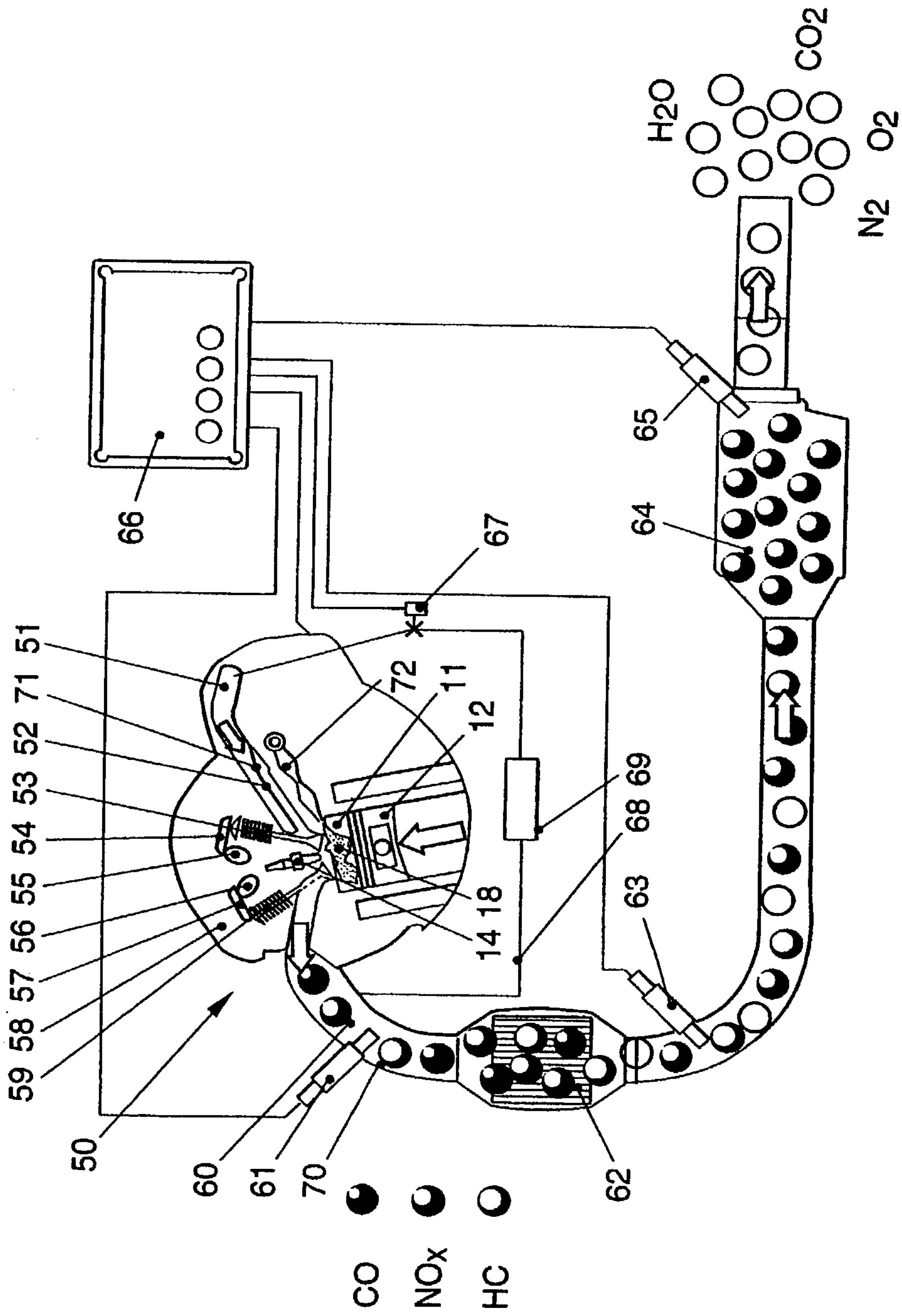
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H_2O
CO_2
O_2
N_2
CO
NO_x
HC

FIG. 4

BAKER BOTTS LLP

DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63)

☐ Declaration Submitted with Initial Filing **OR** ☑ Declaration Submitted after Initial Filing (surcharge (37 CFR 1.16 (e)) required)

Attorney Docket Number	A35111 PCT USA
First Named Inventor	Ekkehard Pott
COMPLETE IF KNOWN	
Application Number	10/089,528
Filing Date	March 27, 2002
Group Art Unit	
Examiner Name	

As a below named inventor, I hereby declare that:

My residence, mailing address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

DIRECT INJECTION INTERNAL COMBUSION ENGINE WITH NOx REDUCED EMISSIONS

(Title of the Invention)

the specification of which

☐ is attached hereto

OR

☑ was filed on (MM/DD/YYYY) 03/27/2002 as United States Application Number or PCT International

Application Number 10/089,528 and was amended on (MM/DD/YYYY) ____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application.

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or (f), or 365(b) of any foreign application(s) for patent, inventor's or plant breeder's rights certificate(s), or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent, inventor's or plant breeder's rights certificate(s), or any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached? YES	NO
			☐	☐	☐
199 48 298.5	Germany	10/06/1999	☐	☐	☑
			☐	☐	☐
			☐	☐	☐

☐ Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto:

BAKER BOTTS L.L.P

DECLARATION Utility or Design Patent Application

Claim for Benefit of Prior U.S. Provisional Application(s)

I hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below:

Provisional Application Number	Filing Date

Claim for Benefit of Earlier U.S./PCT Application(s) under 35 U.S.C. 120

(complete this part only if this is a divisional, continuation or C-I-P application)

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior application(s) in the manner provided by the first paragraph of Title 35, United States Code § 112, I acknowledge the duty to disclose information as defined in Title 37, Code of Federal Regulations, Section 1.56 which occurred between the filing date of the prior applications(s) and the national or PCT international filing date of this application:

Application Number	Filing Date	Status (patented, pending, abandoned)

10089528 .070202

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Attorney Docket Number A35111 PCT USA

DECLARATION Utility ~~or Design~~ Patent Application

Direct all correspondence to: ☑	Customer Number or Bar Code Label: 21003	OR ☑ Correspondence address below	
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City		State	ZIP
Country	Telephone		Fax

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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☐ Additional inventors are being named on the ____supplemental Additional Inventor(s) sheet(s) PTO/SB/02A attached hereto

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BAKER BOTTS LLP

Please type a plus sign (+) inside this box ☐

DECLARATION	ADDITIONAL INVENTOR(S) Supplemental Sheet Page ___ of ___

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Inventor's Signature	Date

Residence: City	State	Country	Citizenship

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City	State	ZIP	Country